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Relationships between multispectral vegetation indices and crop coefficients of *rabi* sorghum

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Abstract: Crop coefficients play an important role for estimation of crop water requirements. Tabulated crop coefficients in FAO publications are time based and lack spatial dimension. Hence, the study was conducted to study the multi temporal spectral behavior of remotely sensed Vegetation Indices (VIs) of *rabi* sorghum and investigate their relationships with the corresponding crop coefficients and selecting best performing relationship in order to estimate spatial water requirement of *rabi* sorghum. The study area consisted of dominant *rabi* sorghum growing five districts situated in central Maharashtra. Images of IRS-P6, AWiFS sensor were used to generate multi-temporal vegetation indices RVI, NDVI, TNDVI, SAVI and MSAVI2. The VIs for each week were correlated with corresponding week crop coefficients of *rabi* sorghum recommended by MPKV Rahuri, which resulted in linear relationships. It was observed that all the vegetation indices follow the same pattern as that of crop coefficients throughout the growing period indicating possibility for building relationship among them. Simple linear regression analysis showed MSAVI2-Kc linear relation as a superior relation for predicting crop coefficients of *rabi* sorghum. This linear relationship showed highest R^2 and D values of 0.805 and 0.943 with lowest values of SE, RMSE and PD of 0.102, 0.096 and 1.76 respectively.

Key words: *Evapotranspiration, water requirement, AWiFS, Maharashtra, LOCATE, ArcGIS*

Introduction

Determination of actual crop evapotranspiration (ETc) is fundamental requirement for accurate irrigation scheduling of crops. For determination of ETc, FAO have recommended to use crop coefficient approach in which ETc is calculated by multiplying a crop coefficient (Kc) by reference evapotranspiration (ETo) (Allen *et al.* 1998). The method of calculation of Kc has been given by Doorenbos and Pruitt (1977). The values of crop coefficient of crops under standard conditions at initial, mid and end season are tabulated. For non standard conditions, FAO have suggested to use corrections and use locally developed Kc values for accurate results. Even, these developed Kc values apply to large areas and are time based. These Kc values lack spatial dimension. These limitations can be overcome by adopting advanced technologies such as satellite remote sensing. Many studies have shown that satellite derived vegetation indices (VIs) can be used for this purpose, considering similarity between the growth pattern of VIs and Kc. Different researchers used VIs for estimation of crop coefficients (Bashir *et al.* 2006; Rahiman *et. al.* 2011; Farg *et al.* 2012) and also crop water requirement for different scales (Jayanthi *et al.* 2000; Gontia and Tiwari 2010; Ozcan *et al.* 2014). This study explores the relationship between crop coefficient (Kc) and various remote sensing derived vegetation indices (VIs) for the *rabi* sorghum crop in Maharashtra so that the best performing relation can be used for calculation of spatial crop coefficients.

Material and Methods

Study area

This study was conducted in five districts situated in central part of Maharashtra *i.e*. Pune, Solapur, Ahmednagar, Beed and Osmanabad wherein spatially, extensive and contiguous land parcels contribute to sorghum production (Fig.1). It covers an area of approximately 65,716 Km^2. It is located between 73°17'19"E to 76°47'42" E longitudes and 19°58'57" N to 17°03'56" N latitudes Most parts of these districts are falling in water scarcity zone with average annual rainfall between 500-700 mm with uncertainty and ill distribution. Rainfall pattern is bimodal. Droughts occur very often. The climate is hot and dry. General topography is having slope between 1-2 %. Most soils are Vertisol and have montmorilonite clay, poor in nitrogen, low to medium in phosphate and well supplied in potash.

Remotely sensed data

Multi-date, multispectral satellite images of IRS- P6, AWiFS (Advanced Wide Field Sensor) Sensor for five consecutive months of *rabi* season (October/November/December /January/February) of the year 2012-13 were used for this study (Table 1). Rectangular subset images covering the study area were obtained and processed in ERDAS Imagine to generate five most commonly used vegetation indices (VIs) *i.e.* Ratio Vegetation Index (RVI), Normalized Difference Vegetation Index (NDVI), Transformed Normalized Difference Vegetation Index (TNDVI), Soil Adjusted Vegetation Index (SAVI) and Modified Soil Adjusted Vegetation Index , 2nd version (MSAVI2) on all the dates of satellite pass (Table 2)

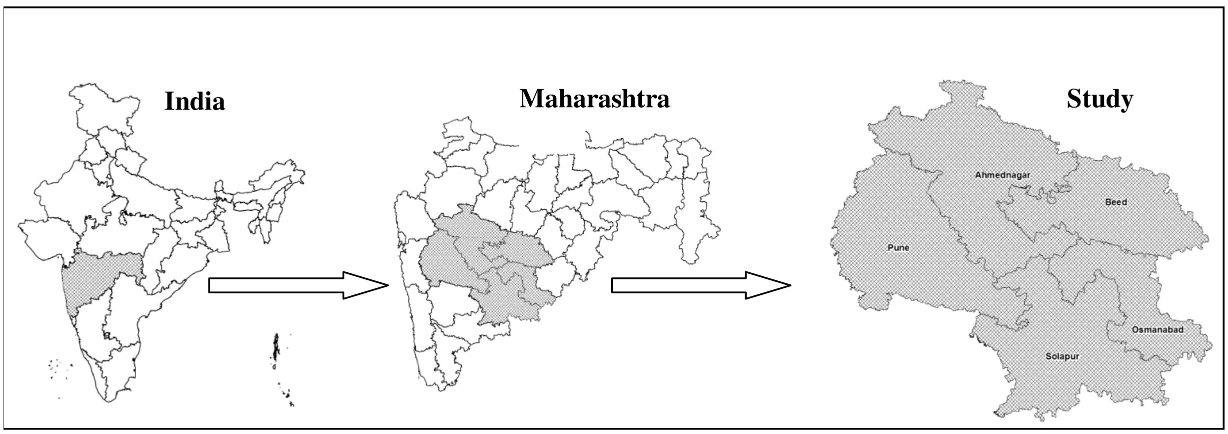


Fig. 1 Location of the study area

Table 1. Multi-date IRS-P6 AWiFS data used for the study

Table 2. Vegetation Indices (VIs) used for study

Sl. No.	Indices	Equation	Reference
1.	RVI	NIR/RED	Jordan (1969)
2.	NDVI	(NIR-R) / (NIR+R)	Rouse *et al.* (1973)
3.	TNDVI	[(NIR - RED)/(NIR + RED) + 0.5]^(1/2)	Tucker (1979)
4.	SAVI	[(NIR - RED) / (NIR + RED + L)] * (1 + L)	Huete (1988)
5.	MSAVI2	$[2*NIR+1-\sqrt{(2*NIR+1)^2 - 8*(NIR-R)}] / 2$	Qi *et al.* (1994)

Ground truth data

Ground truth work was carried out in December 2012 coinciding with the season of *rabi* sorghum crop in the study area. Data were collected from 34 sites of crop spread throughout the study area. Handheld GPS device, geotagged camera and a mobile device with LOCATE software were used to obtain the locations and elevations of the sites. The information obtained from each site was recorded in ground truth proforma sheets. Information on sowing date, variety, probable harvesting date were collected through discussion with the farmer. In absence of farmer indirect method for determining the crop age was followed by referring the criterion suggested by Vanderlip (1993) consultations with experts in the region.

Image processing

Rabi sorghum polygon vector layer was prepared based on the ground truth data in ArcGIS. Images of all the vegetation indices (VIs) on all the dates of pass were generated. Pure *rabi* sorghum multidate VIs were extracted using Signature Editor in ERDAS Imagine software. These VI values were arranged weekwise considering the age of *rabi* sorghum crop at different locations in terms of week. The date of pass 11 December 2012 was taken as reference image date. The age of crop on the dates of pass before and after the date of reference image were determined considering the time lag between the images.

Study of VI growth patterns and establishment of VI-Kc relations

The trend of development of vegetation indices with growing age of *rabi* sorghum were studied. The empirical relationships between weekly *rabi* sorghum crop coefficients (Kc) recommended by Mahatma Phule Krishi Vidyapeeth Rahuri (MPKV 2012) and the values of respective vegetation indices (VIs) were obtained by using linear regression analysis. The relations obtained were evaluated by means of statistical parameters such as coefficient of determination (R^2), root mean square error (RMSE), Willmott Index of agreement (D) and percent deviation (PD). Based on the results of statistical analysis best performing model was selected.

Results and Discussion

The multidate values of pure crop vegetation indices (VIs) obtained were arranged according to the age of crop in terms of week at each location. These values were averaged for each week and thus averaged week values of vegetation indices obtained for *rabi* sorghum are depicted in Table 3. These vegetation indies (VIs) when plotted against weeks past sowing show the pattern of development (trend) of the VIs with growing age of *rabi* sorghum. It is found that almost all the vegetation indices show lower values during initial stages of germination and vegetative growth and reach to their maximum values at 8^{th} or 9^{th} week indicating maximum vegetative growth at booting to anthesis stage. They remain nearly constant and vacillate within a narrow range in 8, 9, and 10th week coinciding mid season (booting, heading and anthesis) stage. After 11th or 12th week all the VIs show decreasing trend indicating yellowing and wilting of the plants. After 17th week these VI show lowest values. When VIs and Kc are together plotted against weeks past sowing, it is observed that the trend of development of all the VI is almost similar to the trend of crop coefficients. The VI sand Kc show similar temporal pattern. (Figs. 2a, 2b, 2c, 2d and 2e).

Table 3. Average weekly values of the vegetation indices of *rabi* sorghum

Week past sowing	Spectral Vegetation Indices				
	RVI	NDVI	TNDVI	SAVI	MSAVI2
2	1.7917	0.2752	0.8777	0.4070	0.4227
3	1.9176	0.2954	0.8900	0.4406	0.4490
4	2.0753	0.3061	0.9158	0.5102	0.5029
6	1.9418	0.3277	0.9000	0.4665	0.4708
7	2.2433	0.3793	0.9341	0.5604	0.5408
8	2.3325	0.3788	0.9406	0.5793	0.5525
9	2.2831	0.3700	0.9396	0.5757	0.5496
10	2.2963	0.3736	0.9366	0.5677	0.5442
11	2.2798	0.3701	0.9288	0.5461	0.5292
12	2.1102	0.3377	0.9158	0.5103	0.5025
13	2.0351	0.3098	0.9097	0.4920	0.4908
14	1.8982	0.2961	0.8944	0.4508	0.4587
15	1.8870	0.2960	0.8861	0.4310	0.4396
16	1.7659	0.2649	0.8736	0.3975	0.5397
17	1.6261	0.2336	0.8577	0.4647	0.3770
18	1.5687	0.2088	0.8422	0.3221	0.4199
19	1.5000	0.2021	0.8314	0.2890	0.3723
20	1.4739	0.1729	0.8262	0.2751	0.3058

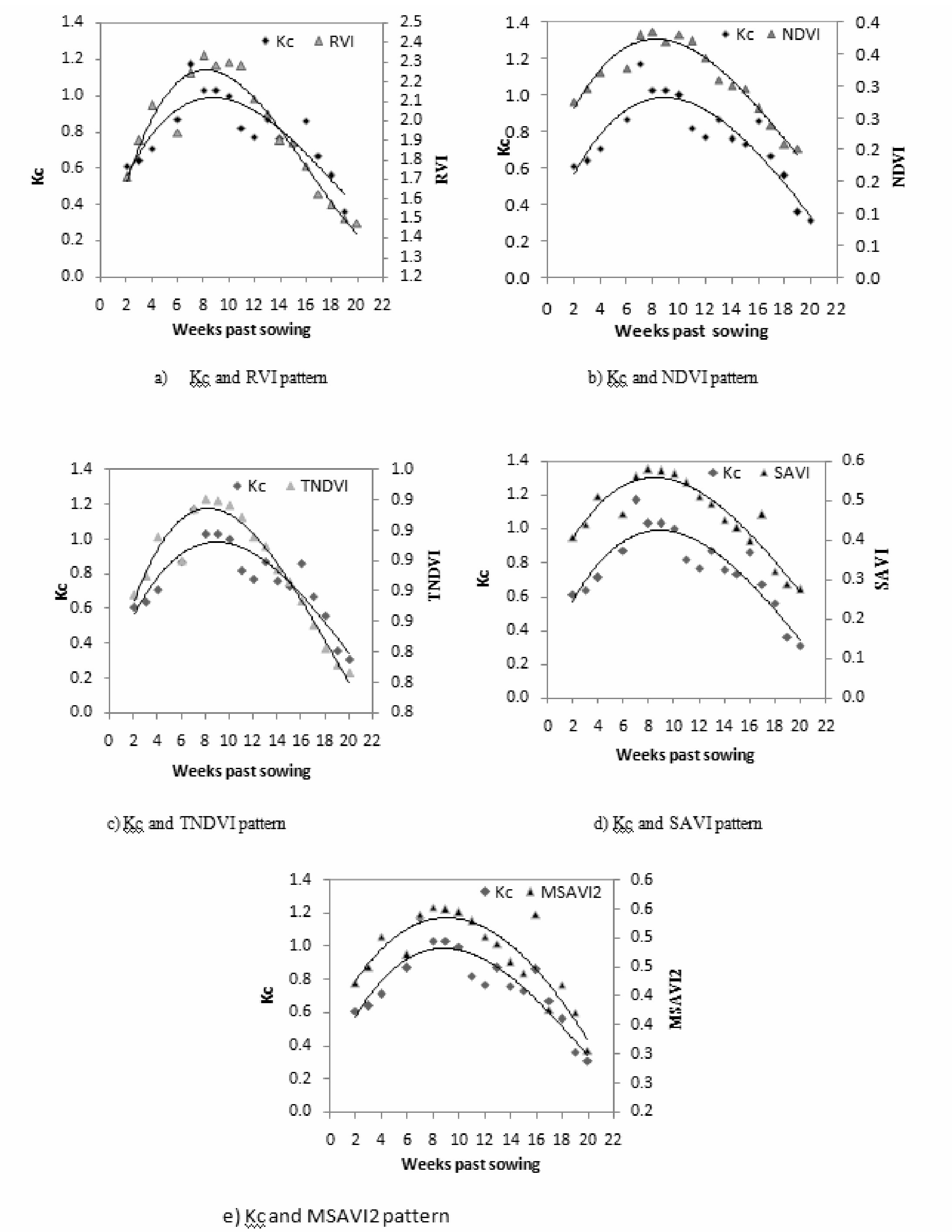


Fig . 2 a,b,c,d and e. Comparison of patterns of Crop coefficient (Kc) and Vegetation Indices (VIs)

Simple linear regression analysis was applied to investigate the relationship between these vegetation indices and crop coefficients. It was observed that a strong correlation existed between all the vegetation indices (VIs) and crop coefficient (Kc) of *rabi* sorghum. Figs. 3a, 3b, 3c, 3d and 3e show relationships of the vegetation indices RVI, NDVI, TNDVI, SAVI and MSAVI2 with the recommended weekly crop coefficients of *rabi* sorghum crop respectively. From the regression analysis linear prediction models were obtained. These prediction models are:

Kc = 0.681RVI - 0.561

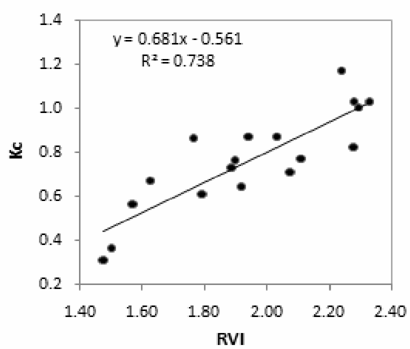
Kc = 3.120 NDVI - 0.172

Kc = 5.362 TNDVI - 4.031

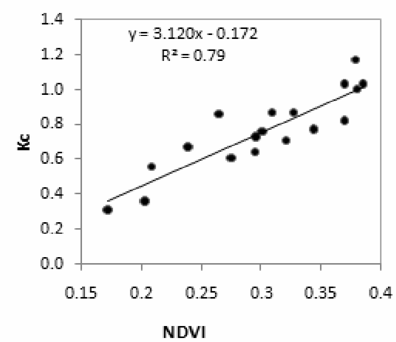
Kc = 2.096 SAVI - 0.200

Kc = 2.838 MSAVI2 - 0.570

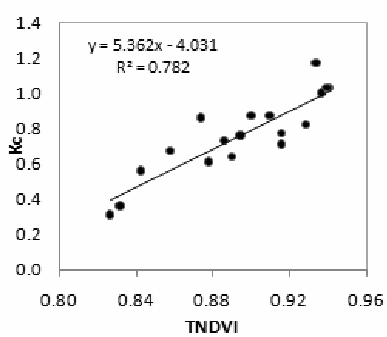
Models generated above were statistically evaluated by most frequently used statistical parameters and are demonstrated in Table 4. It is found that all the vegetation indices (VIs) have reasonably good correlation with sorghum crop coefficients (Kc) with significantly high R^2 values. However, MSAVI2-Kc model showed highest R^2 value followed by NDVI-Kc model with the R^2 values of 0.805 and 0.790 respectively. MSAVI2-Kc model also showed lowest values of SE, RMSE and PD of 0.1022, 0.0960 and 1.76 respectively. MSAVI2-Kc model also showed highest D value of 0.943. This confirms the reasonable performance of MSAVI2-Kc model. Thus, MSAVI2 is best indicator of *rabi* sorghum crop coefficient followed by NDVI.



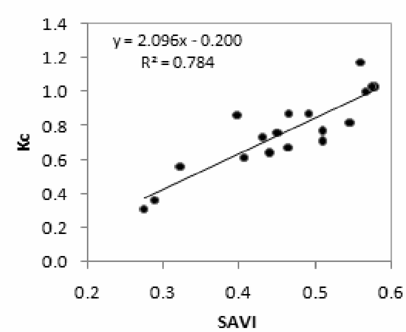
(a) Kc vs. RVI



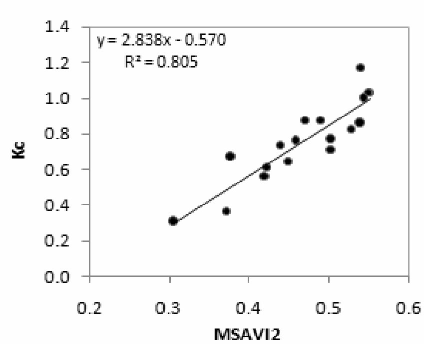
(b) Kc vs. NDVI



(c) Kc vs. TNDVI



(d) Kc vs. SAVI



(e) Kc vs. MSAVI2

Fig. 3 a,b,c,d,and e Relationships of crop coefficients(Kc) with vegetation indices (VIs) for rabi sorghum

The vegetation indices are indicator of greenness and sensitive to photosynthesis and spongy mesophyll structure of leaves. Among these VIs, MSAVI2 incorporates the soil brightness correction factor, automatically reducing the error due to open soil surface between the rows of crop. Sorghum crop is mostly rainfed and plant stand seldom covers complete surface of soil. Therefore, MSAVI2 is of great significance to indicate the vegetative growth and ultimately to represent crop coefficient Kc. The results obtained are supporting the similar studies conducted by Bausch and Neale (1987), Neale *et al.* (1989) for corn, Neale *et al.* (1996), Hunsaker *et al.*(2005) and Singh *et al.* (2013) for cotton, Misra *et al.*(2005) for paddy crop in West Bengal and Ozcan *et.al.* (2014) for wheat in Turkey and Mandal *et.al.* (2007) for sorghum LAI and yield at Hyderabad, India.

Table 4. Results of statistical analysis of VI-Kc prediction models of *rabi* sorghum crop

	Intercept	Coefficient	S.E.	R^2	RMSE	PD	D
RVI- Kc	-0.561	0.681	0.1186	0.738	0.1118	3.09	0.920
NDVI- Kc	-0.172	3.120	0.1034	0.790	0.9750	2.13	0.942
TNDVI - Kc	-4.031	5.362	0.1080	0.782	0.1020	2.31	0.936
SAVI – Kc	-0.200	2.096	0.1077	0.784	0.1010	2.05	0.937
MSAVI2-Kc	-0.570	2.838	0.1022	0.805	0.0960	1.76	0.943

Conclusions

All the VIs and crop coefficients followed the pattern of crop growth. Conversely, phenological information can be tracked from observations of VIs. Probable date of planting can be detected from the defined VI patterns. Similarity in pattern of VIs and Kc indicated that Kc can be modeled in terms of vegetation indices for *rabi* sorghum. MSAVI2-Kc model was found to be highly superior for determination of spatial crop coefficient which can be applied to estimate spatial water requirement of *rabi* sorghum crop.

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